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EFFECTS OF WATER AND NITROGEN APPLICATION ON COMPOSITION, GROWTH, SUGARS IN FRUITS, YIELD, AND SEX EXPRESSION OF THE PAPAYA PLANTS (CARICA PAPAYA L.)

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EFFECTS OF WATER AND NITROGEN APPLICATION ON COMPOSITION, GROWTH, SUGARS IN FRUITS, YIELD, AND SEX EXPRESSION OF THE PAPAYA PLANTS (CARICA PAPAYA L.)

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INTRODUCTION

Fertilizer practices of sugar cane *(2, 3, 4, 5)* and pineapple *(11, 12)* in Hawaii are based, among other things, on leaf chemical analysis. The first step, before such a practice could be recommended for other crops, is to select the index tissues for each constituent. The index tissues, selected for a particular constituent, must necessarily correlate not only with the nutritional level of that constituent throughout the whole plant, but with the important tissues of the plant. Such tissues are the active meristematic tissues of the plant. Second, the optimum levels of each plant constituent for growth and yield are established. Preliminary investigations are underway to select the index tissues in papaya plants. An attempt is made in the experiment reported in this paper to establish optimum level of nitrogen for growth.

Nitrogen is one of the mineral constituents most needed by papaya plants in Hawaii. Growers, almost invariably, apply "mixed" fertilizers containing some form of nitrogen. However, without adequate moisture in the soil and plant, it is unlikely that nitrogen or any other minerals would be absorbed in sufficient quantities.

Another aspect of papaya culture that needs consideration is the seasonal production of various floral and fruit types by papaya plants. It has been reported by some workers that the nutritional status is closely associated with the sexual status in some plants. For instance, Schaffner *(13)* reported that the sexual status in Jack-in-the-Pulpit (*Arisaema triphyllum* (L.) Schott) and in the Green Dragon (*Arisaema dracontium* (L.) Schott) can be controlled by regulating the application of water and keeping these plants at a high nutritional level. Gardner *(7)*, investigating the effect of nutrition in sex expression of strawberry plants, suggests that variations in the relative carbohydrate content of these plants were responsible for the sex expression. In papaya, a study of the effect of nutritional levels on the sexual status would be of physiological interest and agricultural importance.

The experiment reported in this paper was conducted to observe the effects of water and nitrogen, differentially applied, on (1) leaf composition, (2) growth of the plants, (3) concentration of sugar in the fruits, (4) yield, and (5) sex expression of the plants.

MATERIALS AND METHODS

The experiment was conducted under field conditions at the Hawaii Agricultural Experiment Station farm at Poamoho, Oahu. Seeds from hermaphroditic fruits were sowed on May 29, 1943, and the seedlings were transplanted to the field on August 18, 1943. The planting distance was 9 feet between trees and 10 feet between rows.

The factorial type of experimental design, which consisted of three levels of nitrogen and two levels of irrigation, was used. The experiment comprised six treatments and each treatment was replicated three times. Each plot consisted of from five to seven hermaphroditic trees. Although the experiment included female trees, studiẽs were conducted solely on hermaphroditic trees except for the fruit yield data.

The low nitrogen plots received .015 lbs. N./tree/three months or 29 lbs. N./acre/year applied as ammonium sulfate fertilizer. The high nitrogen plots received .06 lbs. N./tree/three months or 116 lbs. N./acre/year. All plots received 228 lbs. K_2O/acre/year and 348 lbs. P_2O_5/acre/year applied as muriate of potash and superphosphate fertilizers, respectively. The rate of application per year was calculated on the basis of 484 trees per acre.

The soil moisture content of the topsoil (6–12 inches depth) maintained in the high and low irrigation plots is presented in figure 1. Permanent wilting percentage and maximum field capacity constants, which were determined of soils belonging to the low humic latosol group, to which Poamoho soils belong *(16)*, were 25.8 percent and 32.0–34.3 percent, respectively. Adequate control of soil moisture content in the high and low irrigation plots was not possible during the winter months due to the relatively heavy rainfall during this season. However, more adequate control of soil moisture was possible during the summer. In any case, a differential of soil moisture content between the low and high irrigation plots was maintained throughout this investigation.

Differential irrigation applications were started on December 4, 1943, approximately four months after the plants were transplanted into the field. Differential applications of fertilizer were started on December 9, 1943. The weighed amount of fertilizer for each tree was placed in equal quantities in each of six holes, which were dug approximately 6 inches deep and 18 inches from the trunk of each tree.

The first leaf sample was collected on December 29, 1943, by which time the trees had one differential application of fertilizer and had been irrigated differently. Leaves were sampled immediately after sunrise in order to minimize the diurnal fluctuation in carbohydrates. They were separated into blades and petioles and weighed in the field. In the beginning, seven leaf blades or petioles constituted a sample, but later when the size of the leaves increased the number of leaves in a sample was reduced to five and finally to two. One leaf was taken from a tree at any one sampling day. Leaves from hermaphroditic trees were sampled only.

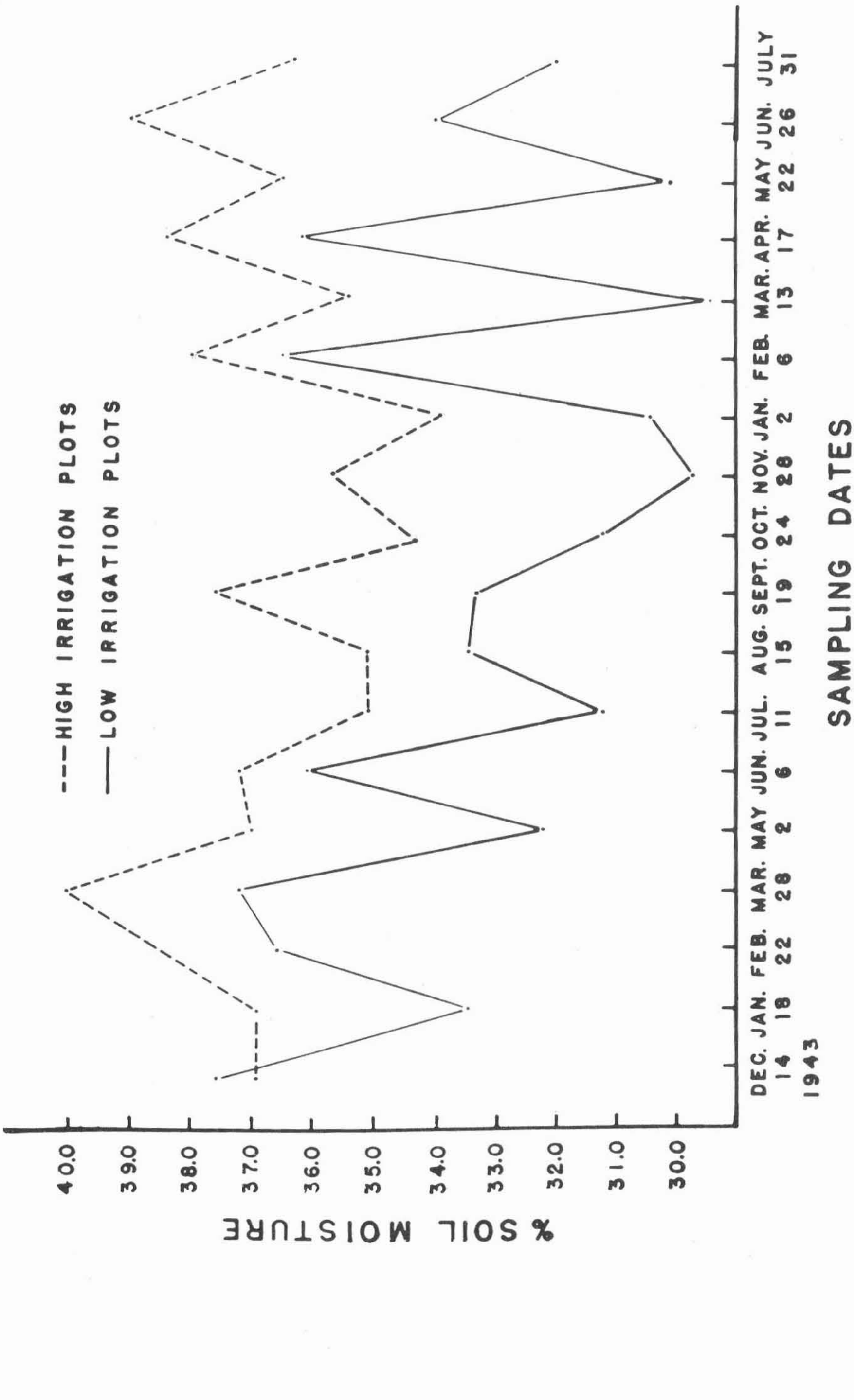

FIG. 1. Soil moisture content of the high and low irrigation plots taken at a depth of 6–12 inches.

The samples were taken into the laboratory where they were sliced with a sharp knife. They were then immediately dried in an air circulating dryer at 85° C. for approximately 30 minutes, after which time the temperature was lowered and maintained at 75° C. until the tissues were completely dried. The samples were weighed to obtain the dry weight, ground in a Wiley Mill using a 20-mesh screen, and stored in stoppered bottles until they were chemically analyzed.

Leaf samples were collected from December 29, 1943, to August 17, 1945, at 35-day intervals. Thus, samples were collected 18 times during this experiment.

The seventeenth leaf from the apex of the plant was sampled for chemical analyses using a petiole approximately 2.5 centimeters long as the reference point. The seventeenth leaf is usually the most recently matured leaf.

The following growth measurements were taken:

(1) Elongation of trunk. Measurements were taken of hermaphroditic trees at monthly intervals for a period of 15 months. The same point near the base of the trunk was used as the reference point for the measurements.

(2) Rate of emergence of new leaves. The number of new leaves that emerged during weekly intervals was recorded. This was determined by selecting a petiole 2.5 centimeters long as petiole A and recording the number of leaves that emerged during weekly intervals between petiole A and the position formerly occupied by petiole A.

Fruit yield was determined at weekly intervals from September 5, 1944, to July 10, 1945. Fruits which were mature, as indicated by the appearance of yellow color on the skin, were harvested. They were segregated into types by plots and weighed in the field. The number of each type was also recorded.

Two ripe hermaphroditic fruits from each treatment were harvested at bi-weekly intervals for the sugar determinations. The skin was peeled and the seeds were discarded. The flesh was homogenized, and an aliquot was taken. All sugar determinations reported in this experiment were made by using the method of Quisumbing and Thomas *(1)*. The concentration of total sugars is expressed as percentage of the fresh weight.

Sugar determinations of the petioles were made by using water as the extracting agent and without the use of lead acetate as a clearing agent. A comparison study conducted on extracting sugar with 80 percent ethyl alcohol and with water, with or without the use of lead acetate as a clearing agent, indicated no significant difference in determinations between the two methods.

Total nitrogen was determined by the nesslerization of ammonia as adapted for plant materials by Lindner *(10)*. Calcium was precipitated as calcium oxalate (CaC_2O_4) and titrated with standard potassium permanganate ($KMnO_4$) *(1)*. Magnesium was precipitated as magnesium ammonium phosphate ($MgNH_4PO_4$) and titrated with standard acid *(8)*. Potassium was determined by the cobaltinitrite method of Volk and Truog *(18)*. Phosphorus was determined by Denige's colorimetric method as modified by Truog and Meyer *(17)*. All the mineral constituents were expressed as percentage of the dry weight. Sugar determinations of leaf tissues were expressed as percentage of the dry weight. Moisture was expressed as percentage of the fresh weight.

Analysis of variance was used to test differences of treatment means except for the data on the concentration of sugars in the fruits. These were tested by pairing the data for each sampling date and the "t" test was applied *(14)*. The statistical method of multiple regression was used to relate certain pertinent factors to growth. Partial regression coefficients of trunk elongation on the various factors were determined in each treatment, and then the procedure was repeated with the treatments combined.

It became necessary, for the present, to use either the petiole or blade of the seventeenth leaf as the index tissue for the various constituents. Clements *et al.* *(3, 4, 5)* determined through extensive study that either the elongating blade (leaf blades of leaves 3, 4, 5, 6; the No. 1 leaf is the emerging spindle leaf), or the green leaf cane blade (all living tissues below No. 6), could be used as the index tissue for nitrogen in sugar cane plants. They have also determined the primary index (total sugars), moisture, potassium, and phosphorus indexes as the concentrations of these constituents in the elongating cane sheaths.

For the present, the petiole was used as the index tissues for total sugars and moisture, and the blade was used as the index tissues for the mineral constituents studied here. These selections were based primarily on the range in concentrations of the various constituents. Trunk elongation was used as the index for growth.

RESULTS

Composition of Tissues

Since the plants did not respond to the nitrogen applications, except for the increase in concentration of this constituent in the tissues, the treatments were reduced to the low and high irrigation plots.

The mean percentage composition of leaf tissues and the difference required for significance of the treatment means are presented in table 1.

The concentration of total sugars in the petiole of the plants in the low irrigation plots was significantly higher at the 5 percent level of probability than that of the plants in the high irrigation plots (table 1). The concentration range of total sugars was 4.24 percent in January 17, 1945, to 21.69 percent in July 26, 1944, in the plants of the low irrigation plots, and 3.85 percent in February 21, 1945, to 19.77 percent in July 26, 1944, in the petiole of the plants in the high irrigation plots.

Both the leaf blade and petiole moisture percentages of the plants in the high irrigation plots were significantly higher at the 1 percent

TABLE 1. Mean Percentage Composition of Leaf Tissues and the Difference Required for Significance of Treatment Means

CONSTITUENTS AND TISSUES	MEAN PERCENTAGE COMPOSITION		DIFFERENCE REQUIRED FOR SIGNIFICANCE	
	LOW IRRIG.	HIGH IRRIG.	5%	1%
Reducing sugars:				
Petiole	8.82	8.42	N.S.*	N.S.*
Total sugars:				
Petiole	12.34	11.56	.61	----
Moisture:				
Blade	78.72	79.63	----	.38
Petiole	88.34	89.10	----	.27
Total nitrogen:				
Blade	4.79	4.94	----	.07
Petiole	1.24	1.16	.08	----
Potassium:				
Blade	1.66	1.94	----	.24
Petiole	1.80	2.28	----	.43
Phosphorus:				
Blade	0.325	0.346	----	.014
Petiole	0.130	0.140	.007	----
Calcium:				
Blade	2.34	2.31	N.S.*	N.S.*
Petiole	1.58	1.66	.07	----
Magnesium:				
Blade	1.31	1.16	----	.14
Petiole	0.73	0.64	.08	----

*Not significant.

level of probability than that of the low irrigation plots. Petiole moisture concentrations in the plants of the low irrigation plots ranged from 86.15 percent in August 30, 1944, to 90.18 percent in February 21, 1945. The concentration ranged from 87.31 percent in October 4, 1944, to 90.45 percent in February 21, 1945, in the petiole of the plants in the high irrigation plots.

Significantly higher concentration of nitrogen at the 1 percent level of probability was indicated in the leaf blade tissue of the plants in the high irrigation plots. Concentrations ranged from 3.30 percent in August 17, 1945, to 6.03 percent in May 17, 1944, in the leaf blades of the plants in the low irrigation plots, and 3.76 percent in August 17, 1945, to 6.08 percent in June 21, 1944, in the high irrigation plots.

Although the plants did not respond to nitrogen applications, the difference in mean concentrations between the control and low nitrogen plots was significant at the 5 percent level of probability. There was no significant difference between the low and high nitrogen plots, although the concentration was higher in the latter plots. The mean concentrations of this constituent in the control, low, and high nitrogen plots were

4.81 percent, 4.88 percent, and 4.90 percent, respectively.

Significantly higher concentration of potassium at the 1 percent level of probability was indicated in both the blade and petiole of the plants in the high irrigation plots. The concentrations of this constituent ranged from 0.91 percent in October 4, 1944, to 2.75 percent in January 17, 1945, in the leaf blade tissue of the plants in these plots. They ranged from 0.51 percent in October 4, 1944, to 2.75 percent in February 21, 1945, in the leaf blades of the plants in the low irrigation plots.

Phosphorus concentration was significantly higher at the 1 percent level of probability in the leaf blade tissues of the plants in the high irrigation plots. In this tissue, the range in concentrations was from 0.222 percent in July 11, 1945, to 0.482 percent in February 21, 1945, in the plants of the low irrigation plots. The concentrations ranged from 0.267 percent in December 29, 1943, to 0.491 percent in February 21, 1944, in the plants of the high irrigation plots.

Calcium concentrations did not seem to be affected by the treatments. The concentrations ranged from 1.67 percent in June 6, 1945, to 3.40 percent in October 4, 1944, in the leaf blade tissue of the plants in both treatments.

Significantly higher concentration of magnesium was indicated in the leaves of the plants in the low irrigation plots. The range in concentrations was from 0.92 percent in June 6, 1945, to 2.10 percent in October 4, 1944, in the leaf blade tissue of the plants in the low irrigation plots. The concentration range in this tissue was from 0.80 percent in May 17, 1944, to 1.74 percent in December 29, 1943, in the plants of the high irrigation plots.

Growth

The difference required for significance of the treatment means on the rate of trunk elongation (table 2) and the rate of leaf emergence (table 3) indicate that, in general, the plants in the high irrigation plots grew more rapidly than those in the low irrigation plots. The difference in growth is especially evident during the summer and fall.

Partial regression coefficients of trunk elongation on age and petiole moisture (table 4) indicate that these two factors were probably two of the more important factors that affected trunk elongation. However, it is quite likely that included in the regression of trunk elongation on age is fruit yield. This becomes clear when it is considered that in the papaya plant, as soon as the fruiting stage is reached, the plant thereafter is almost continuously fruiting normally throughout its productive life. This is likely to depress growth since the fruits and the active meristematic tissues tend to compete for the plant constituents.

Partial regression coefficients of trunk elongation on maximum and minimum temperatures were also determined but were not significant.

TABLE 2. Trunk Elongation and the Difference Required for Significance between Treatment Means Expressed in Centimeters per Four Weeks per Tree

PERIODS OF MEASUREMENT	TRUNK ELONGATION/TREE		DIFFERENCE REQUIRED FOR SIGNIFICANCE	
	LOW IRRIG.	HIGH IRRIG.	5%	1%
March 21 to July 11, 1944	19.27	21.08	1.35	1.88
Aug. 8 to Nov. 28, 1944	8.68	15.20	----	2.67
Dec. 26, 1944 to April 24, 1945	7.34	7.28	N.S.*	N.S.*
May 22 to Aug. 14, 1945	7.74	10.57	----	1.51

*Not significant.

TABLE 3. Leaf Emergence and the Difference Required for Significance between Means Expressed as Number of Leaves Emerged per Week per Tree

PERIODS OF DETERMINATION	LEAF EMERGENCE/WEEK/TREE		DIFFERENCE REQUIRED FOR SIGNIFICANCE	
	LOW IRRIG.	HIGH IRRIG.	5%	1%
Jan. 4 to April 18, 1944	2.37	2.42	N.S.*	N.S.*
May 25 to Aug. 22, 1944	2.68	3.02	----	.17
Aug. 22 to Dec. 26, 1944	2.04	2.37	----	.25
April 24 to Aug. 14, 1945	2.02	2.38	----	.23

*Not significant.

TABLE 4. Partial Regression Coefficients of Trunk Elongation on Age and Moisture with the Multiple Correlation Coefficients (R)

TREATMENTS	AGE β	MOISTURE β	R	N*
Low irrigation	−.782†	+.082	.808†	160
High irrigation	−.812†	−.151†	.832†	161
Low + High irrigation	−.782†	+.092†	.799†	321

*Number of observations.
†Significant beyond 1% level of probability.

This is contrary to the studies of Clements on the growth of sugar cane plants *(6)*, in which he determined that temperature was very closely related to growth of sugar cane plants. Perhaps this is explainable on the basis that the data used in the multiple regression here were not adequately complete to avoid fortuitous relationships. Clements has conducted his studies on sugar cane plantings made at four different times of the year in order to avoid such fortuitous relationships.

Concentration of Sugars in the Fruits

It is the purpose in this phase of the investigation to determine the influence of moisture on the "eating" quality of the fruit.

The "t" value between the concentration of sugars in the fruits of the low and high irrigation plots was 9.237, which is significant beyond the 1 percent level of probability. The percentage of total sugars ranged from 9.64 percent on October 17, 1944, to 11.54 percent on September 19, 1944, in the low irrigation plots, and 8.41 percent on October 17, 1944, to 9.72 percent on February 6, 1945, in the high irrigation plots.

The concentration of sugars in the fruits on the fresh weight basis seems to be inversely related to the moisture level in the plant (table 1). Leaf moisture contents of the plants in the high irrigation plots were significantly higher at the 1 percent level than for the plants in the low irrigation plots. However, if the concentration of sugars was expressed on the dry weight basis, this relationship may not be true.

Yield

The fruit yield per tree and the difference required for significance of the treatment means, based on data obtained weekly from September 5, 1944, to July 10, 1945, are presented in table 5. The type 4 fruit is the "solo" type and is the only hermaphroditic type which is usually marketable. Type 2 fruit is extremely misshapen, while type 3 fruit is less misshapen than type 2 fruit but, nevertheless, is not marketable. The reader is referred to Storey's classification of floral and fruit types *(15)* for detailed descriptions.

Although the yield of hermaphroditic fruits did not seem to be affected to any great extent by the treatments, the trees in the high irrigation plots, nevertheless, produced heavier yield than those in the low irrigation plots. However, when the hermaphroditic fruits were segregated into their component fruit types, yields of types 2 and 3 fruits indicated significant increase at the 1 percent level of probability in the high irrigation plots. No difference in yield of type 4 fruits is indicated between treatments.

Number and Percentage of Each Fruit Type

The number of each fruit type and the difference required for significance between the treatment means based on the data obtained weekly from September 5, 1944, to July 10, 1945, are presented in table 6.

TABLE 5. Fruit Yield per Tree and the Difference Required for Significance between Treatment Means, Expressed in Total Pounds per Tree

TYPE OF FRUITS	POUNDS/TREE		DIFFERENCE REQUIRED FOR SIGNIFICANCE	
	LOW IRRIG.	HIGH IRRIG.	5%	1%
Type 2 fruits	11.05	22.24	----	6.76
Type 3 fruits	45.70	71.61	----	17.70
Type 4 fruits	93.54	94.31	N.S.*	N.S.*
All hermaphroditic fruits	149.03	188.32	N.S.*	N.S.*
Type 1 fruits (female)	113.64	141.96	----	26.59

*Not significant.

The number of fruits of types 2 and 3 increased significantly at the 1 percent level in the high as compared to the low irrigation plots. No difference in the number of type 4 fruits is indicated between treatments.

The percentage of each fruit type and the difference required for significance between the treatment means, based on the data obtained weekly from September 5, 1944, to July 10, 1945, are presented in table 7.

TABLE 6. Number of Each Fruit Type per Tree and the Difference Required for Significance between Treatment Means

TYPE OF FRUITS	NUMBER OF FRUITS/TREE		DIFFERENCE REQUIRED FOR SIGNIFICANCE	
	LOW IRRIG.	HIGH IRRIG.	5%	1%
2	15.28	27.56	----	6.68
3	48.94	72.48	----	17.62
4	91.71	82.42	N.S.*	N.S.*
All hermaphroditic fruits	155.93	182.46	N.S.*	N.S.*

*Not significant.

TABLE 7. Percentage of Each Fruit Type per Tree and the Difference Required for Significance between Treatment Means

TYPE OF FRUITS	PERCENTAGE OF FRUIT TYPE/TREE		DIFFERENCE REQUIRED FOR SIGNIFICANCE	
	LOW IRRIG.	HIGH IRRIG.	5%	1%
2	9.71	15.64	----	5.20
3	31.44	39.68	----	5.20
4	58.85	44.68	----	7.18

Type 4 fruits were produced in greater percentages in the low irrigation plots.

DISCUSSION

An opportunity was presented in this investigation to observe the effects of nitrogen and irrigation applications on composition, growth, concentration of sugars in fruits, yield, and sex expression of the papaya plants. Differential applications of nitrogen did not produce any noticeable effect on the behavior of the plants except to increase the concentration of this constituent in the leaves of the plants in the fertilized plots. Growth behavior of the plants was essentially the same among the differentially applied nitrogen plots. Nor was there any difference in the sex expression of the plants. The yield was not increased with added increments of nitrogen. Thus, it was concluded that the nitrogen level (about 4.81 percent dry weight in leaf blade) of plants in the control plots, was quite adequate to maintain growth and production among the trees.

Irrigation, on the other hand, had definite effects on the behavior of the plants. One of its effects is the composition of the plant constituents in the leaf. The concentrations of nitrogen, potassium, phosphorus, and moisture increased significantly at the 1 percent level of probability in the high irrigation plots. Conversely, total sugars and magnesium concentrations were higher in the low irrigation plots.

It is not surprising, therefore, to notice that plants in the high irrigation plots grew more rapidly than plants in the low irrigation plots. Although the difference in the moisture levels resulted in the difference in growth behavior of the plants, as indicated by the analysis of variance method of statistical analysis, the more dominant factor that affected growth in both treatments, in a negative way, was age, as indicated by the multiple regression analysis. However, perhaps age is partially masking the effect of yield on growth.

The difference in composition and growth among the differentially irrigated plots resulted in increased yield of total hermaphroditic fruits in the high irrigation plots. When the total hermaphroditic fruits were segregated into their component fruit types, type 2 and 3 fruits (carpellodic) indicated significant increase in yield in the high irrigation plots at the 1 percent level of probability. No significant increase in yield of the type 4 fruits (solo) was indicated between treatments.

An interesting result of the treatments is the production of the various fruit types. Plants, in the low irrigation plots, produced type 4 fruits (solo) in greater percentages than plants in the high irrigation plots. This suggests a relationship between the sex status and either of two factors: the moisture level, or growth of the papaya plant. Since the moisture level is closely related to growth of the papaya plants, as indicated by the multiple regression analysis, the grower may be able to control, to some extent, the production of the various fruit types by controlling the application of water and fertilizers.

In this investigation, a beginning has been made in the study of growth and physiological response of papaya plants to fertilizer application, by leaf analysis. It is quite possible that the index tissues used in this study may not be the correct ones; and so, in future investigations, modifications may be in order. Another objective is the establishment of optimum levels of the important minerals and constituents for growth and yield before sound fertilizer practices can be recommended.

SUMMARY

Papaya plants were subjected to differential applications of water and nitrogen under field conditions. Moisture, total sugars, nitrogen, potassium, phosphorus, calcium, and magnesium determinations were made on selected index tissues.

The concentration of the minerals and the moisture content, except calcium and magnesium, in the leaves of the plants in the high irrigation plots were significantly higher than that of the plants in the low irrigation plots. The concentration of total sugars, however, was higher in the low irrigation plots.

The plants in the high irrigation plots indicated a significantly faster rate of growth than that of the low irrigation plots as evidenced by the faster rate of trunk elongation and rate of leaf emergence. By the use of the statistical method of multiple regression, it was determined that the age and moisture level of the plant were two of the more important factors affecting the growth of the papaya plants.

The concentration of total sugars in the fruit, expressed as a percentage of the fresh weight, was significantly higher in the low than in the high irrigation plots.

The yields of hermaphroditic fruits in the high and low irrigation plots indicated greater yield in the high irrigation plots, although this was not statistically significant. When the hermaphroditic fruits were segregated into their component fruit types, it was found that the production of types 2 and 3 fruits was significantly greater in the high irrigation plots, but there was no difference in the yield of type 4 (solo) fruits.

The number of types 2 and 3 fruits (carpellodic) increased significantly at the 1 percent level in the high irrigation plots. No difference in the number of type 4 fruits was indicated between treatments.

The percentage of types 2 and 3 fruits was significantly higher in the high than in the low irrigation plots; the percentage of type 4 fruits, however, was significantly higher in the low irrigation plots. This suggests a relationship between sex expression and either the moisture level or growth of the plant.

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